



Ionic (Proton) Transport Hydrogen Separation Systems

Summary Session



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Performance Goals

High hydrogen flux at low pressure drop	200 scfh/ft ² (100 ml/cm ² /m) upper limit for ITM
Tolerance to contaminants	Homogeneous (HCN, phosphene, COS, Ar, NH ₃ , CO, CH ₄ , H ₂ S, others); Assume particulates, ash, etc have been removed upstream. Need to quantify how clean the syngas is (application specific).
Low cost	< \$100/ft ² for integrated ITM module
Operation at high temperatures	250-350°C (integrated with WGS – may not be purely ITM) 800-1000°C (Natural gas, coal or biomass gasification)
High durability	4-5 years (5 years upper limit) (100,000 hrs is 12 years)



Performance Goals

Robust operation in unstable, harsh environments	Yes
Low parasitic power	2.8 kWh/1,000 schf (Should be translated into more understandable efficiency losses – 1%, 2%)
Maintenance of material integrity at high ΔP as well as ability to operate at required conditions	800 -1,000 psi
Ability to produce pure hydrogen	99.99% (Need specific list of contaminants for PEM and other applications)
Hydrogen recovery	Application-specific – needs to be quantified
Ability to be integrated into one-step reactor unit	Yes - this is controlled by mass transport issues
Ability to operate in unit producing compressed permeate	This is already covered under flux parameter



Technology Options -- Ionic Transport Separation Systems

Option	Pros	Cons
Central, Semi-Central (coal, natural gas, biomass)		
Possible technology options: O ₂ ITM (In development); H ₂ ITM (R&D Phase); CO ₂ ITM (concept); PSA not cost-effective at this scale	High selectivity, stability, purities, durability, possible co-production, flexibility, ease of catalyst introduction	Scalability, lower flux, pipeline transport required (NIMBY issues), low H ₂ production with some options, may require downstream separation



Technology Options -- Ionic Transport Separation Systems

Option	Pros	Cons
Distributed Systems (natural gas, liquid HCs)		
ITM replacing PSA	High selectivity, stability, durability possible cost advantages	Lower flux
WGS Integrated System	Lower noise, less complex, easier to put catalyst on surface than PD membrane	Matching kinetics effectively
Reformer +ITM (no WGS)	high temperature advantage	Highly oxidizing conditions



Top Priority Barriers – Ionic Transport Separation Systems

Central/Semi-Central Systems

- Coal is the cheapest fuel, but requires the greatest pre-conditioning
- Clean-up of syngas requires thermal oscillations (cool down, heat up)
- Scalability – fabrication at large scale is very complex, requires skilled craftsmen (no industrial base exists)



Top Priority Barriers -- Ionic Transport Systems

Distributed Systems – Integrated WGS or Reformer + ITM (no WGS) based on natural gas or liquid hydrocarbons

- Integrated reactor concepts have numerous barriers/challenges
 - Incomplete understanding of integrated ITM system
 - Unknown theoretical limits of ITM
 - Capital efficiency for integrated membrane reactor will be a design issue
 - Poor understanding of mass transfer limitations
- Must be more robust to handling cycling at fueling stations (shut-down, start-up, membrane replacement)



Top Priority Barriers -- Ionic Transport Systems

General ITM Challenges

- Current techniques for identifying, screening new materials are tedious and time consuming
- Flux is limited
- ITMs tend to be less robust
- Cost of sealing module



Top Priority R&D Needs – Ionic Transport Separation Systems

Central/Semi-Central Systems

- Cleanup and conditioning of syngas
 - Hot gas cleanup (need to evaluate current work in this area)
 - Better understanding of gas cleanup process and potential electrochemical poisoning mechanisms
 - Preconditioning of coal-based streams
- Large test bed facilities accessible to users
- Process models for larger scale systems (H₂ production)



Top Priority R&D Needs – Ionic Transport Separation Systems

Distributed Systems

- Explore challenges to integrated reactor design (e.g., mass transfer issues)
- Reliability engineering studies for modular systems at fueling stations



Top Priority R&D Needs – Ionic Transport Separation Systems

- Exploration/identification of entirely new material concepts/classes
 - High throughput testing
 - Screening for proton conductivity
 - Screening for host of other parameters (stability, reaction with CO₂ and steam, chemical expansion/contraction, etc
 - Reduction in time for testing
 - New families of ceramics
 - Establish metrics for different applications



Top Priority R&D Needs – Ionic Transport Separation Systems

- Improve ITM system robustness
 - Accelerated aging tests
 - Failure mode prediction
 - Reliability analysis
- Develop better predictive models
 - Modeling of both process and membrane (device and process)
 - Prediction of thermal cycling and other performance parameters
 - Economic models for process and manufacturing
 - Property data development and model validation



Top Priority R&D Needs – Ionic Transport Separation Systems

- First explore systems that are easiest to attain (H_2 from Nat Gas), then move on to liquid HC, then coal



Take-Away Messages

- More than one approach to producing/separating H₂
- No silver bullet
- Using ITM systems will require a mix of materials exploration, process development, and testing methodologies
- Targets will vary and depend on: feed source, different process components, application, etc
- Temperature models for the process are needed to fully explore potential membrane applications